Risk assessment for a UK pan-European Supergrid

Eskandari Torbaghan, Mehran; Burrow, Michael; Hunt, Dexter

DOI:
10.1002/er.3365

Document Version
Peer reviewed version

Citation for published version (Harvard):
Eskandari Torbaghan, M, Burrow, M & Hunt, D 2015, 'Risk assessment for a UK pan-European Supergrid', *International Journal of Energy Research*, vol. 39, no. 11, pp. 1564-1578. https://doi.org/10.1002/er.3365

Title: Risk assessment for a UK-Pan European Supergrid

Abstract

Interconnected electricity networks, Supergrids, are being considered to help tackle some of the current global energy challenges such as rising CO_2 emissions and the complete reliance on renewables. However, there are a range of obstacles associated with developing interconnections, not least the uncertainties associated with selecting appropriate countries with which to make interconnection. The process of identifying and then assessing various risks for these interconnections can be considered to be an important factor in mitigating and controlling their impact from within and outside national and international boundaries.

To this end, this paper presents a risk-based framework to identify and assess the risks associated with developing new interconnections with other countries. Expert's knowledge and information available from the literature were used to identify 19 construction and 11 maintenance risks and to rank them using a 'risk' matrix. The usefulness of the approach is demonstrated using the UK as the case study. The analysis of the identified risks showed that Regulatory framework, Changes in energy policy and Weak onshore grids require special attention and that of those countries considered, Ireland was deemed to have the lowest risk for interconnection with the UK.

1. Introduction

As part of current and future energy policy a number of countries worldwide are adopting, or proposing, policies to encourage the development of cross-border connections for the supply of energy. These interconnections, as they will now be referred to, are seen as a viable means of tackling some of the obstacles to wider utilisation of renewable energy resources. These include, for example, their intermittency, variability and cyclic nature (Chatzivasileiadis *et al.*, 2013; Elliott, 2013). In Europe the Supergrid, as it is known, is capable of transmitting power from renewable sources using a High Voltage Direct Current (HVDC) grid spread across the European continents and beyond. The distinct advantage of such a system is that it improves the security of energy supply by providing parallel-multiple supply paths connecting countries across different time zones, with different electricity generating profiles, consumption demands and patterns (Van Hertem and Ghandhari, 2010; Hirschhausen, 2012). This offers a distinct array of benefits whereby the Supergrid can reduce the overall cost for generating electricity within the whole system thereby decreasing the requirement for other sources of spare energy capacity, which tend to be carbon emitting fossil fuels.

The concept of the European Supergrid is seen as part of the process of creating a single carbon reduced market for electricity across European Union member countries (European Commission, 2007). In February 2011, the European Council agreed upon an ambitious objective to complete the single energy market by 2014, however, due to slow progress by member countries, this has been significantly delayed (European Union, 2014). One of the barriers to progress is the need for cross-border investment in energy infrastructure including the physical interconnections (Brancucci Martínez-Anido *et al.*, 2013; European Commission, 2014). Further, the associated decision-making process is often a protracted procedure, for example on-going negotiations about developing interconnections have been continuing for over 10 years between France and Spain, and the UK and Norway. Part of the reason for such lengthy negotiations is because of the uncertainties involved. These include, but are not limited to: changes in energy policy of the countries concerned; the availability of spare electricity; security of supply issues; the comparatively lengthy construction period and the life-time of the physical interconnections.

Such uncertainties could be addressed via a suitable risk management process that enabled for identifying, better understanding and mitigating the potential impacts of risks (Flyvbjerg *et al.*, 2003; Infrastructure Risk Group, 2013). Appropriate risk assessment in this context would create a common language between all engaging countries that would help resolve disputes and shape a set of common priorities, thereby facilitating the overall decision-making process (Linkov and Ramadan, 2006).

This paper describes the use of a risk assessment procedure that is adopted in order to tackle one of the major issues associated with any Supergrid, in other words the process '*for identifying suitable partner countries with which to make an interconnection with in order to enable renewal energy to be imported'*.

Early stage risk-assessment can significantly reduce the cost of projects by restricting unnecessary spend, especially with contingencies allocated for cost uncertainty (Infrastructure Risk Group, 2013). However, a major challenge of carrying out a risk analysis for the process of constructing interconnections is obtaining reliable information (in terms of identifying risks, and then assessing their likelihood of occurrence and impact) because such construction projects are essentially one-off enterprises (Flanagan and Norman, 1993). To overcome this an established methodological approach is to make use of knowledge obtained from a diverse range of experts in the field, who are well versed in terms of experience, judgment and application of rules-of-thumb (Dikmen *et al.*, 2007). Accordingly this paper utilizes such expert opinion and enables early stage risk assessment to be undertaken in the appraisal stage of a project. The innovative methodology presented herein focuses on risk identification and assessment of related impacts using a range of experts' opinion, the process is demonstrated by considering interconnections between countries in continental Europe and the UK.

2. Risk assessment and its implication for interconnections

A number of approaches to deal with uncertainty associated with energy related projects are described in the literature, see for example Song et al. (2013) and Kearns et al. (2012). However, literature dealing specifically with the risks and uncertainties of interconnections is less well developed. An exception is the study described by Parail (2010b) where interconnections are considered in terms of an economic risk associated with electricity trading on financial markets. Unfortunately it does not take into account other uncertainties such as those associated with social, technical, environmental and political factors. A shortfall which this paper aims to fill. Understanding the construction and maintenance risks of an interconnection requires comprehending their causes, and likelihoods and consequences of occurrence to adopt appropriate mitigation measures. In conventional risk assessment these are typically considered as part of a framework which consist of three main processes namely (BSI, 2010);

1. risk identification, (Section 3.2)
2. semi-quantification (Section 3.3) and
3. quantification.

Risk identification is the process of finding, recognising and recording risks whilst semi-quantification and quantification stages are about determining the consequences and likelihood of occurrence for identified risk events.

In the case of interconnections, the identified risks are directly related to, or influenced by, project complexity, construction time (up to 10 years for some seabed interconnections), the duration of asset use (40 years or more), and the involvement of various industries and stakeholders. An interconnection project is notoriously risky because two countries are involved, each with their own energy related policies and associated politics (Eskandari Torbaghan *et al.*, 2014).

3. Interconnection risk assessment process

The early stage risk assessment process developed herein, utilizes expert opinion to facilitate the identification and assessment of risks for establishing interconnections between the UK and continental Europe and consists of 3 principal stages, i) Initial screening, ii) risk identification, and iii) risk semi-quantification. These are shown in Figure 1.

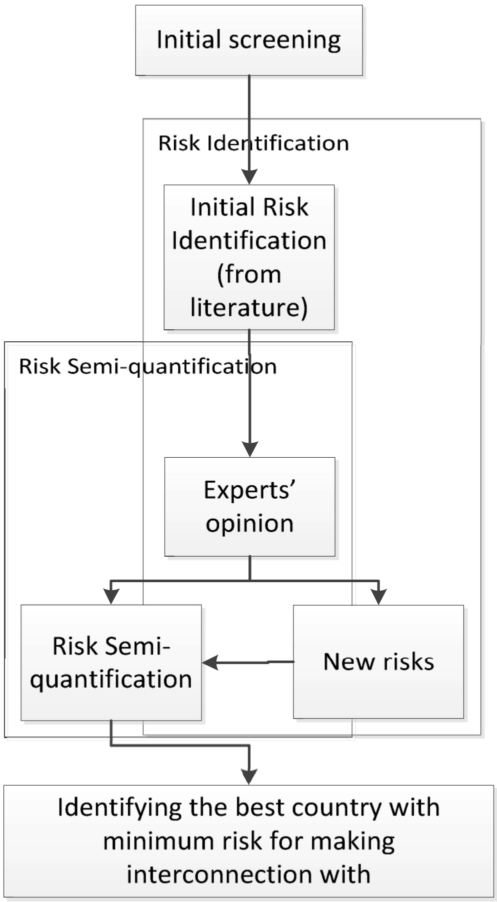

Figure 1. The methodology of study including the risk assessment stages

3.1 Initial screening

An initial screening exercise was undertaken by which unsuitable countries were identified and excluded from further analysis. This process, described further by Eskandari Torbaghan et al. (2014), takes into account political, economic, environmental and social factors to identify candidate countries. Accordingly, 9 feasible candidate countries for interconnection with the UK were identified, these are: Norway, Sweden, Denmark, Germany, Netherlands, Belgium, France, Spain and Ireland.

3.2 Risk identification

The risk identification stage is the process of finding and recognising risks by identifying the circumstances that might affect the availability and security of interconnections and importing electricity (BSI, 2010).

Initially, an extensive literature review was undertaken to identify the most prominent risks and thereafter this was augmented by canvassing the opinion of a group of experts, through a series of structured interviews. In total over one hundred experts from continental Europe, who have specialist skills and knowledge in electricity generation and distribution, were contacted through email correspondence. Of these 20 agreed to partake in the research, representing 8 different countries. These included those working in electricity generating and distribution companies, design engineering consultants, academic researchers of note in their field (including energy policy specialists, electrical power engineers and economists), policy makers and government advisors. The respondents were subsequently grouped into 5 broad categories: Academia, Grid operators, Government advisors, Private developers and Suppliers as shown in Table 1.

Table 1. Breakdown of Experts consulted according to country (a) and Category (b)

Countries	Number of participants
UK	9
Netherlands	2
Italy	1
Belgium	3
Sweden	1
Ireland	2
Germany	1
France	1

(a)

Category	Number of participants
Academia	8
Grid operator	4
Government advisor	5
Private developer	2
Supplier	1

(b)

To facilitate the risk identification process, two main categories were adopted; construction and operation. These were further broken down into 5 sub-categories that depict drivers of change, namely: social, technical, economic, environmental and political (STEEP). A total of

30 risks related to new interconnection were identified (19 associated with construction and 11 with operation. These are summarised in tables 2a and 2b respectively.

3.2.1 Considered risks

Further analysis related to the identified risks was carried out, prior to the risk semi-quantification stage, in order to identify those to be included for further analysis. Only those considered to be different between any of the countries, in terms of either their impact or probability of occurrence, were included.

Table 2.a Identified risk associated with the construction of an interconnection

Risk category	Identified risk	Risk description	Risk Impact	Primary sources	Suggested sources of information
Social	Public acceptability	Public reaction to the investment in making an interconnection and/or its environmental impacts	The cost of running a protracted enquiry, negative publicity, coverage and the possibility of potential cable route change	Expert opinion	
Technical	a. Loss of Dynamic Positioning (DP)	Storms, excessively large waves or currents may prevent the cable laying vessel from keeping its position	Increasing the time and therefore the cost of laying power cables	Worzyk (2009)	
	b. Earthquake	Earthquake might cause seabed displacement induced by fault movement, submarine landslides and seabed soil liquefaction	Cost of adoption of earthquake resistant construction methods and cables.	Aiwen (2009)	Simkin et al. (2006) for Hot spots
	c. Anchoring damages, kinks and loading/re-loading	Risks related to installation and cable laying procedure	Extra costs of cable installation and delay	Worzyk (2009)	
	d. Seabed topography	Existence of boulder fields and a rocky / irregular seabed can raise the cost of the required cable trenching.	Cost of conducting an analysis of the seabed and appropriate measures to avoid or deal with the effect of the rocky seabed	Expert opinion	MESH (2014) for seabed map
	e. Seabed contamination	Oil and gas fields are sources of underwater contamination	Cost of cleaning or avoiding	Liang et al.(2009)	DECC (2014) for UK offshore infrastructures
	f. Unforeseen ship wrecks and other submarine debris	The presence of large ship wrecks may necessitate a change in the proposed route for the cable	Cost of removing or avoiding	Expert opinion	European Marine Observation and Data Network (2011) for map
	g. Unforeseen sea depths	Unpredicted sea depths during the installation or the need to conduct additional measurements due to the existence of unmapped zones	Additional cost during installation and/or design of the cables	Expert opinion	
	h. Weak onshore grids	Weaker infrastructure at the connection points to the grids might lead to further costs to upgrade the system	Increase in construction cost	Expert opinion, (Ayodele *et al.*, 2012; Ibrahim *et al.*, 2012)	
	i. Regulatory framework	Differing regulatory frameworks between the UK and a candidate country	Additional costs required to introduce an entity or vehicle to operate the new interconnection	Expert opinion	Hendriks et al.(2010) for literature review
	j. Marine activities	Fishing nets or anchors can lead to seabed cable failure. This may require heavily fished areas or busy sea lanes to be avoided or special mitigation measures to be put in place	Cost of mitigation or avoidance	(CIGRÉ, 2009; Karlsdóttir, 2013)	International Maritime Organization (2013) for regulations, European Commission (2011) for map of activities
Economic	a. Uncertainty in cost estimation (quantity and rates)	Since building interconnections is a relatively uncommon activity few companies will have had the experience of being involved in such projects. Cost estimation amongst bidders could therefore be expected to be exaggerated since the risk to company in terms of unknowns is high.	Increase in construction cost	Flyvbjerg (2006)	ENTSO-E (2012) for list of existing interconnections

	b. Supply chain; contractor	Lack of competition between contractors (see item a above)	Direct increase in construction cost	Expert opinion	
	c. Solvency of contractor	Contracting firm becomes insolvent	Time delay costs	Expert opinion	Eurostat (2013b) for European countries financial data
	d. Inflated bid price	Due to uniqueness of job	Increase in construction cost	Narayanan (1999)	
	e. Capital and material costs	Capital and material costs may increase during the project abnormally due to economic and political factors.	Increase in construction cost	Decker et al. (2011)	
Environmental	a. Disturbing habitats and ecosystems	Cost of mitigation or avoidance (long term impacts)	Increase in construction cost	Van den Hove et al (2007)	
	b. Climate change	Cost of studies to identify possible impacts of climate change (e.g. on currents; direction and strength and waves) and associated measures to mitigate against them	Increase in construction cost (predesign phase)	Expert opinion	
Political	Changes in energy policy of target country	Changes in energy policy or government by the candidate country may lead to the imposition of higher taxes or charges	Increase in energy cost	Expert opinion	

Table 2.b Identified risk associated with the operation of an interconnection

Risk category	Identified risk	Risk description	Risk Impact	Primary sources	Suggested sources for data collection
Social	Demonstrations caused by an increase in the price energy	In the event of energy becoming more expensive, there is a risk that public demonstrations could occur in both countries involved	Imposing a financial restriction on operation and or maintenance cost	Expert opinion	Parail (2010a) on impacts of interconnections on electricity prices
Technical	a. Availability of electricity from renewable resources	The risk depends on the energy generating characteristic of both the source and target countries taking into account the intermittency of renewables. There is also a risk that national governments may not export energy at times of high domestic demand and low supply (political risk)	Power blackouts in importing country	Expert opinion	
	b. Earthquake		Maintenance of minor damage	Expert opinion	
	c. Marine activities	Fishing gear or anchors can lead to seabed cables failures	Maintenance costs	(CIGRÉ, 2009; Karlsdóttir, 2013)	International Maritime Organization (2013) for regulations, European Commission (2011) for map of activities

	e. Weak onshore grids	Weak infrastructure at the connection points to the grids can lead to loss of electricity	Loss of income due to electricity loss	Expert's opinion and also (Ayodele *et al.*, 2012; Ibrahim *et al.*, 2012)	
Environmental	a. Disturbing habitats and ecosystems	Cost of avoiding disturbing existing or new habitats formed in the vicinity of cables during maintenance	Increase in maintenance cost caused by mitigating the impact of maintenance on the habitats	Expert opinion	
	b. Climate Change	Maintenance to infrastructure required to repair damaged caused by severe waves or currents	Increased maintenance costs	Expert opinion	(Nelson *et al.*, 2009; Greenberg *et al.*, 2012) about impacts on oceans currents and tides
Economic	a. Increase in prices of imported electricity	Caused by changes in energy policy or Customer Duty with a direct impact on the price of electricity and decrease in interconnection revenue	loss of profit	Expert opinion	Eurostat (2013a) on electricity price history
	b. Competition between interconnections	The new interconnections built in the future between the exporting country and another country may have an impact on the availability of RE and also its cost relative to other sources of electricity	Reduction in the return on investment of the interconnection	Expert opinion	Parail (2010b) and Decker et al. (2011) on the economic impacts of the new interconnections on the existing one
Political	a. Changes in energy policy	Changes in policy by respective governments may lead to potential reductions in electricity exported or imported	Shortage of imported electricity, with a consequential increase in electricity price	Expert opinion	
	b. Security of renewable energy supply	The political instability of energy producing countries, manipulation of energy supplies and terrorism	Shortage of imported electricity, with an associated increase in electricity price, blackout, increased costs of maintenance and increased security costs	Wesley (2007)	Battaglini et al. (2010) on countries as reliable electricity supply

Those with similar impacts or probabilities for all considered countries were not included since they would not affect the identification of the country with the lowest risk. Nevertheless their identification is important since they can be used for individual risk assessment for each country. The selected risks are shown in Table 3. For example, “Security of renewable energy supply” was not considered further as its impact and probability was considered to be very similar for the countries considered.

Table 3. List of considered risks for further analysis

Construction risks	Social	Public acceptability
	Technical	a. Loss of Dynamic Positioning (DP)
		b. Earthquakes
		c. Seabed topography
		d. Seabed contamination
		e. Unforeseen ship wrecks and other submarine junk
		f. Unforeseen sea depth
		g. Weak onshore grids
		h. Regulatory framework
		i. Marine activities
	Economic	a. Uncertainty in cost estimation (quantity and rates)
		b. Supply chain; contractor
		c. Solvency of contractor
		d. Inflated bid price
		e. Cost of material
	Environmental	a. Disturbing habitats and ecosystems
		b. Climate change
	Political	Changes in energy policy of target country
Operational risks	Social	Demonstrations caused by raised price
	Technical	a. Availability of electricity from renewable resources
		b. Earthquake
		c. Marine activities
		e. Weak onshore grids
	Environmental	a. Disturbing habitats and ecosystems
		b. Climate Change
	Economic	Increase in prices of imported electricity

3.3 Risk Semi-quantification

The base measure of risk (Equation 1) was used to evaluate respective impacts and probabilities of occurrence (BSI, 2010):

$$Risk = (probability \times impact) \tag{1}$$

Impacts and probabilities were obtained after consultation with the 20 experts who were asked to rate the impact and probability of each of the risks in Table 3 on an integer scale from 1 to 5, with each integer representing a range of possible values as shown in Figure 2. The probability and impact were determined by taking the average response from the experts consulted. This is directly in line with current risk analysis practice when using expert opinion (BSI, 2010).

The resulting matrix of possible risks, determined according to Equation 1, is shown in Figure 2. Scores of 15 or greater were considered to be 'high risk', those equal or greater than 5 but less than 13 were considered to be 'medium risk', whilst scores less than 5 were assumed to be 'low risk'.

			Risk Probability				
			Very Low (≤ 10%)	Low (10-30%)	Moderate (30-50%)	High (50-70%)	Very High (70% or higher)
			1	2	3	4	5
Risk Impact	Very High	5 (higher than £150m)	5	10	High risk 15	20	25
	High	4 (£60m to £150m)	4	8	12	16	20
	Moderate	3 (£30m to £60m)	3	6	Medium risk 9	12	15
	Low	2 (£10m to £30m)	2	4	6	8	10
	Very Low	1 (less than £10m)	1	Low risk 2	3	4	5

Figure 2. Example of the Risk matrix used in semi-quantification stage

4. Results

Table 4 shows for each identified risk scores the scores obtained for the 9 countries considered according to 'Construction Risks' (i to xvii) and 'Operational Risks' (xviii to xxvi). It can be seen that of the 234 possible identified risk-country combinations, around 68% have low risk scores, 32% have medium risk scores and 0% have high risk scores.

Table 4. Results of semi-quantification stage for the candidate countries

RISK TYPE	COUNTRY									AVERAGE
	Norway	Sweden	Spain	Denmark	Germany	Netherlands	Belgium	Ireland	France	
i. Public acceptability	5	5	4	5	6	5	3	5	6	5
ii. DP	2	2	2	1	2	1	1	1	1	1
iii. Earthquake	0	0	0	0	0	0	0	0	0	0
iv. Seabed topography	1	2	3	2	2	3	2	1	2	2
v. Seabed contamination	3	4	2	3	3	4	3	1	2	3
vi. Ship wrecks	2	2	2	2	2	1	1	1	1	2
vii. Unforeseen sea depth	1	0	0	0	3	0	0	2	0	1
viii. Weak onshore grids	5	8	5	7	7	8	8	5	7	7
ix. Regulatory framework	6	9	8	8	8	8	10	10	9	8
x. Marine activities	3	5	4	3	3	3	4	4	6	4
xi. Cost estimation	7	8	9	6	6	6	5	6	7	7
xii. Supply chain	4	4	4	4	3	2	3	2	2	3
xiii. Solvency of contractor	1	2	5	2	1	2	3	3	3	2
xiv. Inflated bid price	5	5	6	4	4	3	5	4	4	4
xv. Cost of material	3	4	3	3	3	3	3	3	4	3
xvi. Disturbing habitats	6	5	3	4	4	4	3	2	4	4
xvii. Climate change	5	5	4	4	4	4	4	2	4	4
xviii. Changes in energy policy	8	8	9	7	9	9	8	7	10	8
xix. Demonstrations	1	1	1	1	1	2	2	1	2	1
xx. Availability of electricity	4	4	8	4	6	7	5	2	6	5
xxi. Earthquake	0	0	1	0	0	0	0	0	0	0
xxii. Marine activities	3	3	3	3	2	2	3	3	3	3
xxiii. Climate Change	2	2	2	2	2	3	2	1	1	2
xxiv. Weak onshore grids	4	5	5	4	8	5	5	7	3	5
xxv. Disturbing habitats	4	5	4	5	3	3	3	2	3	4
xxvi. Increased electricity prices	6	2	7	6	7	7	6	5	5	6
SUM	91	100	104	90	99	95	92	80	95	

: Low Risk : Medium Risk : High Risk

The highest individual risk scores are associated with the regulatory framework (ix in list, with Ireland and Belgium each scoring 10) and changes in energy policy risk (xviii in list, with France a scoring 10).

Assuming risks had an equal weighting they were summed down columns to give a total risk for each country (Section 4.1) and averaged across rows to find a measure for Risk Type (Section 4.2).

4.1 Risk by Country

Figure 3 shows total risks according to each country - ranked in order from highest to lowest.

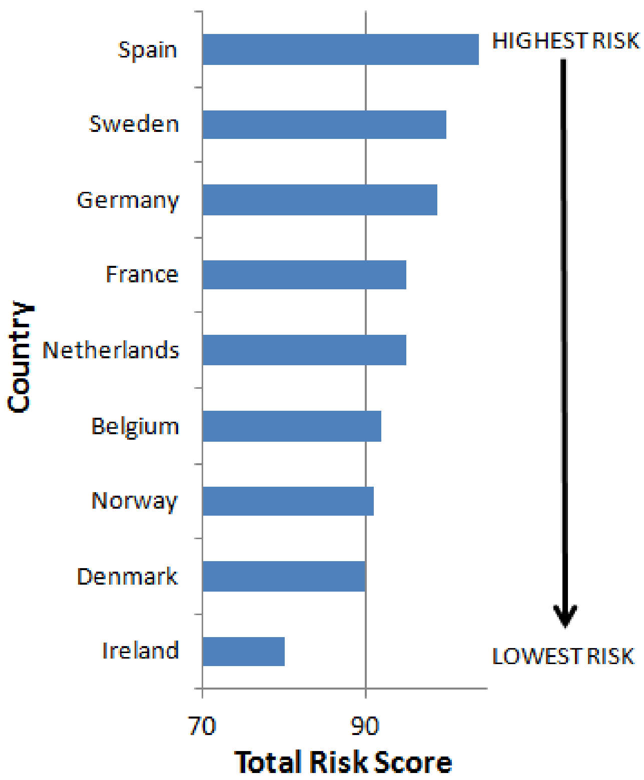

Figure 3. Risk by Country (Ranked in order)

When considering interconnections with the UK, Spain was found to pose the greatest overall risk (i.e. sum for column = 104), whilst Ireland posed the lowest overall risk (i.e. sum for column = 80) - suggesting strongly that Ireland could be considered as a preferential country for the UK to make an interconnection with, whilst Spain is the least preferred. Much of the reasoning for this is related to its proximity to the UK and the relatively well mapped ocean (the Irish Sea) between the two countries highlighted with low risk scores associated with the sea or seabed (i.e. iv to vii in Table 4). In addition to the comparatively short distance between Ireland and the UK (Table 5), its energy and distributing system is similar to the UK and therefore it has low risk scores associated with “increased electricity prices (xxvi in Table 4)” and “changes in energy policy (xviii in Table 4)”.

Table 5. Identified countries and their proximity to the UK

	Countries	Min distance to the UK (km)
1	Sweden	800
2	Spain	700
3	Denmark	580
4	Norway	460
5	Germany	380
6	Netherlands	170
7	Belgium	98
8	Ireland	85[a]
9	France	40

a) Distance by sea

Conversely the comparatively large distance (Table 5) and expanse of ocean between Spain and the UK is a major factor in highest risk ranking (Figure 4). The distance between Sweden and the UK, which is the largest of the countries considered, is also a major factor and contributes towards it having the second highest total risk score of 100 (Table 4 and Figure 3).

Whilst France is the closest country to the UK an interconnection between the two countries has the 4th highest risk score. This is because the socio-political environment in France was considered by the experts to be more volatile than in any of the other 8 countries. For example, risks associated with ‘public acceptability’, ‘the regulatory framework’, and ‘changes in energy policy’ (6, 9, and 10 respectively) are the highest, or amongst the highest, of all countries considered (Table 4).

Nevertheless, whilst most of the identified risks are either low or medium, the fact that the UK currently does not have any under construction interconnection with any other country, despite an identified need, and the ongoing protracted negotiations (see section 2) suggests that regulatory and changes in energy policy risks are perhaps the most influential risks as far as decision makers are concerned.

4.2 Risk by Type

Figure 4 shows average risks (by type) ranked in order from highest to lowest.

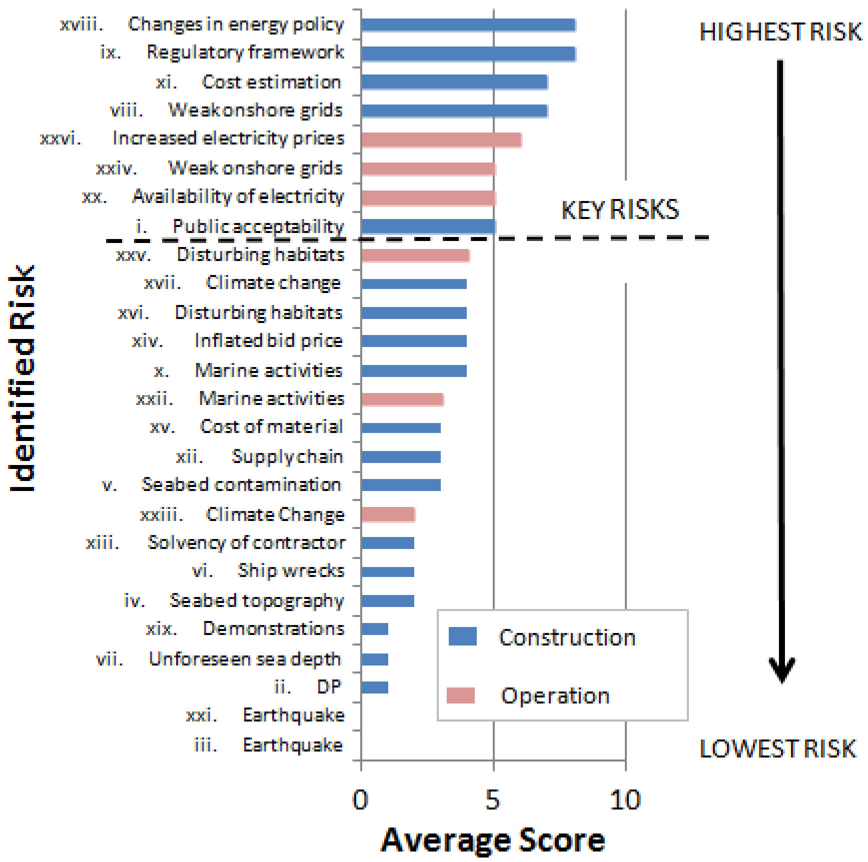

Figure 4. Risk by type (Ranked in order)

In terms of the 'construction category' it can be seen that the highest average risk scores (i.e. 8 - medium risk) are held jointly for 'changes in energy policy' and 'regulatory framework' In terms of the operational risk category 'increased electricity prices' receives the highest average score (i.e. 6 - medium risk). This is related to various external influences such as daily and hourly auctioning. This is not surprising as existing electricity trading system cause uncertainties related to the pricing of electricity, and these are exacerbated where interconnections exist. This risk can be better controlled through adoption of fixed pricing strategies (i.e. via long term contracts).

Key Risks are those that may require mitigation measures to reduce their probability of occurrence and or impact. Unfortunately there is no widely recognised system to identify such key risks. Therefore by using the risk ranking process described (and given that no risk was ranked as high) it was decided that for the purpose of this work ‘key risks’ were those with an average score of 5 or greater (indicated by those located above the dashed line in Figure 4). These top seven risks are discussed further below in their respective ranked order.

4.2.1. Changes in energy policy (construction)

It is not surprising to see this as the top ranked risk. In part because any change in energy policy of the exporting country may impact the availability of renewable energy and can threaten the feasibility of a project during inception. This may be caused through the pressure of public opinion (see 4.2.7), such as has happened in Germany after the Fukushima nuclear disaster in Japan which has caused Germany to adopt policies that sort to reduce its nuclear energy capability. The knock-on effect of Germany’s new energy policy is that it has less available renewable energy to export because of the necessity to use it to replace nuclear energy sources. Consequently we see that Germany, in terms of energy policy risk, was assessed as having one of the highest risk scores (Figure 3 and Table 4).

In addition it is not inappropriate to assume that the imposition of new energy policies might also lead to higher taxes or charges on exports for that country therefore increasing the cost to the UK. The risk is identified as comparatively high for all the countries considered (with risk scores of between 7-10) with France being the highest ranked, and Ireland and Denmark the lowest. Interviews with experts revealed that *“the history of France of not completing interconnection projects”* was the main reason for it being considered the most risky. Conversely, *“the similarity in energy policies”* between Ireland and the UK was the reason why experts considered it to have the lowest risk associated with regards to energy policy (Table 4).

4.2.2. Regulatory framework (construction)

Different existing regulatory frameworks between countries forming a new interconnection, requires the introduction of a joint organisation to build that interconnection. This of itself is logistically complex causing delays and additional costs when trying to obtain the required approvals. The underground Eurotunnel crossing can be cited as an example of a physical interconnection between countries which highlights such delays (almost 50 years in this case). In the pan-European transmission system this is being addressed by the development of a unified regulatory framework of national and regional grid codes, which take into account grid connection charging methods (Hendriks *et al.*, 2010). However, due to dissimilarities in the existing regulatory frameworks in these countries the interdependency between technical (e.g. voltage, and regulatory aspects in Europe a complete accomplishment of a unified framework) has yet to be achieved (Hendriks *et al.*, 2010).

As far as the regulatory framework is concerned, the risk analysis scored all of the candidate countries similarly (with risk scores of 8 to10 excepting Norway with 6.

4.2.3. Cost estimation (construction)

A major source of risk in any project is the inaccurate forecasting of projected costs and construction duration and therefore the predictions of benefits vs costs can be inappropriately judged (Flyvbjerg, 2006). Generally, those countries with a high number of existing interconnections could be regarded to have the least cost estimation risk since they are likely to be the most experienced within this field and more than able to provide an appropriate amount of historical data for the estimation. Table 6 shows the number of seabed interconnections for the nine countries considered in this study (see ENTSO-E, (2012)), from which it can be seen that on this basis Sweden and Denmark should have the least cost estimation risk as they each have seven existing interconnections and three under construction, whilst Belgium with no current interconnections could be considered the most risky.

Table 6. Number of seabed interconnections for nine candidate countries

Country	Number of seabed interconnection	Comments
Sweden	10	Including 3 under construction
Denmark	10	Including 3 under construction
Spain	7	Including 5 under construction
Norway	4	Including 1 under construction
Germany	3	Including 1 under construction
France	3	-
Netherlands	2	-
Ireland	0	1 Under construction
Belgium	0	-

Interestingly however nearly all experts when interviewed suggested that Belgium and Spain were the least and highest risks countries respectively. This is surprising given that Belgium currently has no interconnections, however the experts' suggested that the ranking reflected the country's *"good reputation in the energy sector"*. As for the Spain, the distance between it and the UK, (it is the second longest as mentioned above) as well as the "*financial* *instability"* of Spain's economy were the reasons for the experts assigning it the highest cost risk.

4.2.4. Weak onshore grids (construction and operation)

Connection points are usually located away from the main areas of population where access to a strong grid, with required physical properties (e.g. voltage to connect with the interconnection), is limited. It is well known that weaker infrastructure at the connection points can lead to additional cost requirements in order to upgrade the grid to avoid the risk of losing the entire capacity which might threaten the network stability (Ibrahim *et al.*, 2012). Voltage fluctuation due to load fluctuation in a weak grid can be magnified which can aggravate the power quality problem (Ayodele *et al.*, 2012). Improving the grid at a connection point including construction of new grid is capital intensive but may often be unavoidable. Hence the fact that this is the fourth highest risk is not surprising. The analysis suggests that Sweden, Netherlands and Belgium are perceived to be the most risky in terms of proving access to a strong grid. ENTSO-E (2012) provides information on the existing, under construction and planned electricity infrastructure for all European countries. From this source of information, Table 7 shows the number of existing grid connection points, in each candidate country, located on a coastline facing the UK. Assuming this is an indicator of strong connecting points for a new interconnection it can be seen therein that Sweden and Belgium could be considered to be the least appropriate a fact which has been corroborated by the findings of the experts (Table 4).

Table 7. Number of interconnections and grid branches facing the UK for nine candidate countries

Country	Number of connection points
France	>10
Spain	>10
Norway	6
Netherlands	4
Germany	4
Ireland	4
Denmark	3
Sweden	2
Belgium	1

Spain, Norway and Ireland were identified as being the least risky by the experts which, for certainly the former two countries, is confirmed by the information given in Table 7. The overriding reasons for excluding France have already been mentioned in 4.2.1.

4.2.5. Increase in imported electricity prices (construction)

The impacts of any increase in prices of the exported electricity can be significant on electricity consumers in the importing country. Not least because a historical (i.e. previous 10 years) look at electricity pricing of the candidate country can be used as an indicator of the future price rises of its electricity. The electricity prices for household consumers of the nine considered countries over a 12 year period are shown in Figure 5, from which it may be seen that Ireland has experienced the greatest increase (approximately 130%), whilst Norway has had the greatest fluctuation in price over this period. Although the prices shown in Figure 5 concern the domestic market, and in some countries the cost may be subsidised by the tax payer, they still may be regarded as a useful indication of energy prices across the patch.

However, the experts on the contrary considered that Sweden (Table 4) was the least risky in terms of future increases in electricity cost, whilst France was rated as the 2nd country with a comparatively high score of 5. Spain, Germany and Netherlands were considered to be the riskiest countries with an average risk score of 7. This shows the importance of compiling both historical information and expert opinion before decisions are made.

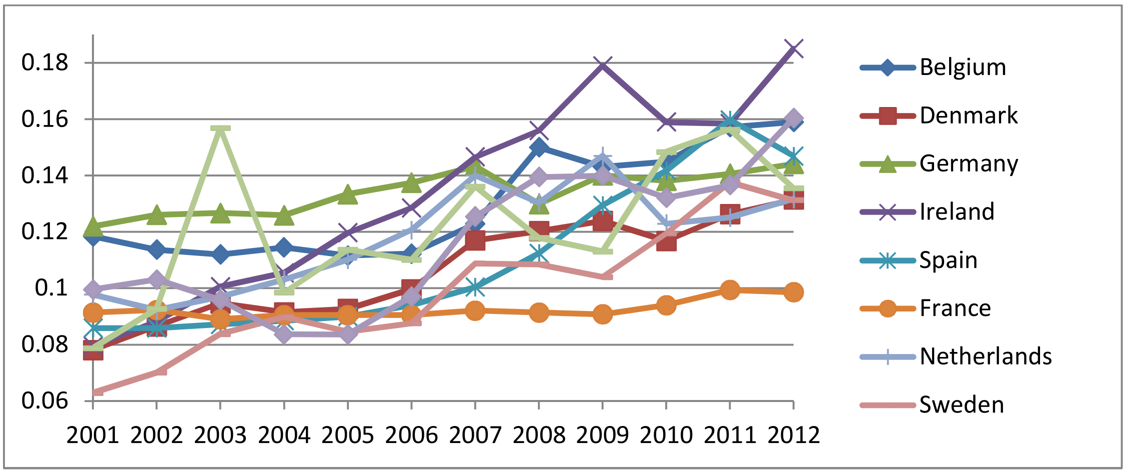

Figure 5. Electricity price history for 9 candidate countries and the UK (€ / kWh) (Eurostat, 2013a)

4.2.6. Availability of electricity from renewable resources (operation)

This risk depends greatly on the energy generating characteristic(s) of the target country and considers the intermittency of renewable supplies. For example, importing electricity from a country which relies primarily on wind to generate electricity may be considered risky as there is no guarantee for supply when of the availability of wind power is highly variable. A more diverse supply stream might be considered less risky in this respect.

On this basis, Table 4 shows Ireland (with a risk score of 2), and Spain, (with a risk score of 8), as the lowest and highest ranked countries in terms of availability of supply from renewables. This is not surprising since Spain obtains a large proportion (around 40% (MINETUR, 2011)) of its energy from both hydroelectric and wind power and is likely to replace (or at the very least supplement) much of its hydroelectricity capacity with solar energy in the future (Energynautics GmbH, 2011), thereby, providing a measure of diversity. Notwithstanding, Spain's future energy policy associated with developing renewables in the future is identified as the main reason for selecting the country as the riskiest by the experts (Section 4.2.1).

4.2.7. Public acceptability (construction)

Public acceptability regarding the investment in making an interconnection and also its environmental impacts are sources of uncertainty for the project. The possible impact can be the cost of running a public enquiry, negative publicity and media coverage and could result in a potential cable route change. For example, public demonstrations that occurred to protest against the environmental impacts of Westernlink (an interconnection being built between Western Scotland and the North Wales) caused the relocation of 4km cable.

According to the experts the public acceptability risk is lowest for Belgium with a score of 3, whilst Germany, which has *"a strong public energy lobby",* and France, which appears *"reticent to develop interconnections",* have the highest score of 6.

5. Concluding Discussion

This paper has presented a risk based framework for identifying the most appropriate country (ies) with which to make grid interconnections and from which to import renewable electricity. It consisted of:

(1) an initial screening process to identify countries to be excluded from further analysis,

(2) a risk identification process to identify threats associated with both building interconnections and importing electricity, and

(3) a risk semi-quantification stage which consisted of determining consequences and probabilities of occurrence to define a level of risk.

The methodology was demonstrated using the UK as a case study and by considering 9 potential host countries. This helped showcase the inherent need for such a tool and highlighted the benefits in terms of informed decision-making that can be reaped. As the developed methodology can be used for building new interconnections it is directly relevant for any country, organisation and or company from public or private sectors to identify the most appropriate country to connect with. This becomes readily apparent when it is used to identify the highest and lowest potential risks associated with construction and operation.

As far as the risk identification process is concerned, the opinion of a group of experts was canvassed to identify the risks. As adopted within this risk assessment methodology this should be considered as a precursor within any risk analysis work and should occur in the initial stages of the project. The results obtained however will ultimately depend upon the range and quality of the experts considered, in our case we would suggest both diverse and high.

When applying risk quantification, our analysis identified that Spain is potentially 'most risky' and Ireland 'least risky' country for the UK to form an interconnection Spain is ranked as the most risky country because of uncertainties in its regulatory framework, cost estimation, changes in energy policy and availability of electricity, whereas Ireland was shown to be least risky because of relatively low risks associated with seabed contamination, environmental impacts, changes in energy policy and availability of electricity. The second most appropriate country identified is Norway, with its vast supply of renewable hydroelectricity and confirms why it already has established interconnections with other countries (e.g. with the Netherlands (NorNed)).

In terms of the individual risks, 8 were identified as 'key risks', in other words those which may require special mitigation measures to be undertaken. Of these 'regulatory framework' and 'changes in energy policy' have the highest average scores and arguably these two politically associated risks may be the main reasons why the UK has yet to establish a new energy interconnection. To address this it is recommended that a pre-study phase in any interconnection project should address any possible differences associated with the energy regulators in each country, in advance and as part of appraisal phase, so that a mutually acceptable framework for the electricity trading can be established at an early stage. As for the energy policy especially regarding the willingness for developing interconnections, and to avoid the current protracted procedures for governmental approvals, engagement of the private sector, through mechanisms such as public private partnerships (PPPs) can facilitate the procedure by providing know how, capital and by reducing some of the risk from the public sector. Furthermore, future changes in energy policy might threaten the availability of tradable renewable electricity. Nevertheless the current trend for developing renewables seems to address this risk and arguably reduce its probability. Engagement of the private sector in developing renewables may also reduce the probability of this risk occurring and may even enhance the development of interconnections to provide a larger market for renewables.

The risk semi-quantification process described herein can be regarded as a first, albeit important stage in analysing the risks associated with interconnections. It is recognised that further refinement of the modelling process is both desirable and necessary. To this end future development of the model will include a refined quantification process, consideration of the relative weights of the identified risks (rather than identical weightages as considered here), with perhaps more weighting given to political risks, and consultation with a wider pool of experts.

Acknowledgements

The School of Civil Engineering at the University of Birmingham is thanked with gratitude for funding this research through a Post-Graduate Teaching Assistantship. In addition the Engineering and Physical Sciences Research Council (EPSRC) are thanked for funding Dr Dexter Hunt under the current Liveable Cities (EP/J017698) programme.

References

Aiwen L (2009) Response analysis of a submarine cable under fault movement. *Earthquake engineering and engineering vibration* **8(1)**: 159-164.

Ayodele TR, Jimoh A, Munda JL andTehile AJ (2012) Challenges of Grid Integration of Wind Power on Power System Grid Integrity: A Review. *International Journal of Renewable Energy Research (IJRER)* **2(4)**: 618-626.

Battaglini A, Lilliestam A and Knies G (2010) The SuperSmart Grid – paving the way for a completely renewable power system. In *Global Sustainability: A Nobel Cause*.(H. Schellnhuber, M. Molina and N. Stern, (Eds.)). Cambridge University, Cambridge, UK, Vol.pp. 288-305.

Brancucci Martínez-Anido C, Vandenbergh M, de Vries L*, et al.* (2013) Medium-term demand for European cross-border electricity transmission capacity. *Energy Policy* **61(2013)**: 207-222.

BSI (2010) BS EN 31010:2010: *Risk management: Risk assessment techniques*. BSI Standards Publication, London, UK.

Chatzivasileiadis S, Ernst D and Andersson G (2013) The Global Grid. *Renewable Energy* **57(2013)**: 372-383.

CIGRÉ (2009) *Third-party damage to underground submarine cables*. CIGRÉ, France.

DECC (2014) *UKCS Offshore Infrastructure***.** Department of Energy and Climate Change, London.

Decker JD, Kreutzkamp P, Joseph P andWoyte A (2011) *Offshore Electricity Grid Infrastructure in Europe: A Techno-Economic Assessment*. OffshoreGrid, Brussels.

Dikmen I, Birgonul MT and Han S (2007) Using fuzzy risk assessment to rate cost overrun risk in international construction projects. *International Journal of Project Management* **25(5)**: 494-505.

Elliott D (2013) Emergence of European supergrids – Essay on strategy issues. *Energy Strategy Reviews* **1(3)**: 171-173.

Energynautics GmbH (2011) *European grid study 2030/2050*. energynautics GmbH, Germany.

ENTSO-E. (2012) *ENTSO-E Grid Map* Brussels, Belgium. See https://www.entsoe.eu/publications/grid-maps/ (accessed 20/10/2014).

Eskandari Torbaghan M, Hunt DVL and Burrow M (2014) Supergrid: projecting interconnection capacities for the UK. *Proceedings of the ICE - Engineering Sustainability* **167(6)**: 249-263.

European Commission (2007) *Third Internal Energy Market Legislative Package, European Commission 2007 Directives and Regulations, as Endorsed in April 2009 by the European Parliament***.** IP/07/1361. European Parliament. europa.eu, Brussels.

European Commission. (2011) *Global Ship Density* Brussels. See https://webgate.ec.europa.eu/maritimeforum/system/files/AIS_Issue3_AllShip_densityMap_0.pdf (accessed 8/2/13).

European Commission. (2014) *Single market for gas & electricity* Brussels. See http://ec.europa.eu/energy/gas_electricity/index_en.htm (accessed 20/01/2014).

European Marine Observation and Data Network. (2011) *Pilot portal for Hydrography* See http://portal.emodnet-hydrography.eu/EmodnetPortal/index.jsf# (accessed 26/07/2011).

European Union (2014) *Internal Energy Market*. European Union, Brussels.

Eurostat. (2013a) *Electricity prices for household consumers* See http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&plugin=1&language=en&pcode=ten00115 (accessed 14/05/2013).

Eurostat. (2013b) *GDP per capita in PPS* See http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tec00114 (accessed 23/09/2013).

Flanagan R and Norman G (1993) *Risk Management and Construction*. Blackwell, Bath, UK.

Flyvbjerg B (2006) From NOBEL Prize to project management: Getting risks right. *Projetc Management Journal* **37(3)**: 10.

Flyvbjerg B, Bruzelius N and Rothengatter W (2003) *Megaprojects and risk: an anatomy of ambition*. Cambridge University, Cambridge, UK.

Greenberg DA, Blanchard W, Smith B andBarrow E (2012) Climate change, mean sea level and high tides in the Bay of Fundy. *Atmosphere-Ocean* **50(3)**: 261-276.

Hendriks RL, Gibescu M, Roggenkamp MM andKling WL (2010) Developing a transnational electricity infrastructure offshore: Interdependence between technical and regulatory solutions. In *Power and Energy Society General Meeting, 2010 IEEE. Minneapolis, MN., USA*. http://ieeexplore.ieee.org, pp. 1-6.

Hirschhausen Cv (2012) Developing a Supergrid. In *Harnessing Renewable Energy in Electric Power Systems: "Theory, Practice, Policy"*.(B. Moselle, J. Padilla and R. Schmalensee, (Eds.)). Taylor & Francis, London, UK, Vol. 1.pp. 181- 206.

Ibrahim RA, Hamad MS, Dessouky YG andWilliams BW (2012) A review on recent low voltage ride-through solutions for PMSG wind turbine. In *2012 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM 2012). Sorrento, Italy*. http://ieeexplore.ieee.org, pp. 265-270.

Infrastructure Risk Group (2013) *Managing Cost Risk & Uncertainty In Infrastructure Projects*. The Institute of Risk Management London, UK.

International Maritime Organization. (2013) *AIS transponders* London. See http://www5.imo.org/SharePoint/mainframe.asp?topic_id=754 (accessed 7/2/13).

Karlsdóttir SH (2013) *Experience in transporting energy through subsea power cables: The case of Iceland*. Industrial Engineering, Mechanical Engineering and Computer Science. University of Iceland, Reykjavik, Iceland Masters**:** 85.

Kearns JO, Thomas PJ, Taylor RH andBoyle WJO (2012) Comparative risk analysis of electricity generating systems using the J-value framework. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* **226(3)**: 414-426.

Liang Y, Li G, Van Nostrand JD*, et al.* (2009) Microarray-based analysis of microbial functional diversity along an oil contamination gradient in oil field. *FEMS microbiology ecology* **70(2)**: 324-333.

Linkov I and Ramadan AB (2006) *Comparative Risk Assessment and Environmental Decision Making*. Kluwer Academic Publishers, Dordrecht, Netherlands

MESH. (2014) *MESH webGIS* http://www.searchmesh.net/default.aspx?page=1546 (accessed 07/04/2014).

MINETUR (2011) *LA ENERGÍA EN ESPAÑA*. MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO, Madrid.

Narayanan R (1999) Information production, insider trading, and the role of managerial compensation. *Financial Review* **34(4)**: 119-144.

Nelson KC, Palmer MA, Pizzuto JE*, et al.* (2009) Forecasting the combined effects of urbanization and climate change on stream ecosystems: from impacts to management options. *Journal of Applied Ecology* **46(1)**: 154-163.

Parail V (2010a) Can merchant interconnectors deliver lower and more stable prices? The case of NorNed. In *Cambridge working papers in economics*. Faculty of Economics, University of Cambridge, Cambridge Vol. 0947.pp. 54.
Parail V (2010b) *Properties of Electricity Prices and the Drivers of Interconnector Revenue*. Faculty of Economics, University of Cambridge, Cambridge, UK.
Simkin T, Tilling RI, Vogt PR*, et al.* (2006) *This Dynamic Planet; World Map of Volcanoes, Earthquakes, Impact Craters, and Plate Tectonics* http://pubs.usgs.gov/imap/2800/ (accessed 8/2/2013).
Song J, Song D, Zhang X andSun Y (2013) Risk identification for PPP waste-to-energy incineration projects in China. *Energy Policy* **61(2013)**: 953-962.
Van den Hove S and Moreau V (2007) *Deep-Sea Biodiversity and Ecosystems: A Scoping Report on Their Socio-Economy, Management and Governanace*. UNEP World Conservation Monitoring Centre, Cambridge, UK.
Van Hertem D and Ghandhari M (2010) Multi-terminal VSC HVDC for the European supergrid: Obstacles. *Renewable and Sustainable Energy Reviews* **14(9)**: 3156-3163.
Wesley M (2007) *Power plays: Energy and Australia's security*. Australian Strategic Policy Institute, Barton, Australia.
Worzyk T (2009) *Submarine Power Cables: Design, Installation, Repair, Environmental Aspects***.** Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg**:** digital.